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Envisioning Artificial Intelligence Possibilities for Tracking *Eidolon Helvum* Bats: A Review

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Abstract: Artificial intelligence (AI) is rapidly assuming significant responsibilities because it can be used to curate data on wildlife observations, migration patterns, ecological population monitoring, and behavior understanding. In this study, current trends in how artificial intelligence is used to understand activities of *Eidolon helvum* fruit bats are discussed. This study reviewed 122 publications related to bats and their environment. Of these publications, only 20 (16%) used machine learning to assess bat activities ranging from specie classification to sound signal processing. In addition, we listed the most widely used machine learning methods and justified their application to ecological research. Furthermore, the study identified other AI-based technology like edge computing and the internet of things (IoT) as new opportunities in ecological research. In conclusion, this study anticipates the joint use of cutting-edge technologies such as TinyML for ecological research and conservation and the need for innovative methods and AI-driven solutions to track wildlife demographics.

Keywords: artificial intelligence, ecology, biodiversity, pattern recognition, wildlife.

展望人工智能追踪幻灵赫尔瓦姆蝙蝠的可能性：综述

摘要：人工智能(人工智能)正在迅速承担起重要的责任，因为它可用于整理野生动物观察、迁徙模式、生态种群监测和行为理解的数据。在本研究中，讨论了人工智能如何用于了解幻灵赫尔维姆果蝠活动的当前趋势。本研究回顾了122篇与蝙蝠及其环境相关的出版物。在这些出版物中，只有20篇(16%)使用机器学习来评估蝙蝠活动，从物种分类到声音信号处理。此外，我们列出了最广泛使用的机器学习方法，并证明了它们在生态研究中的应用。此外，该研究还确定了其他基于人工智能的技术，如边缘计算和物联网(物联网)，是生态研究的新机遇。总之，本研究预计TinyML等尖端技术将联合用于生态研究和保护，并需要创新方法和人工智能驱动的解决方案来追踪野生动物人口统计数据。

关键词：人工智能、生态学、生物多样性、模式识别、野生动物。

1. Introduction

Bats occupy a strategic position in our ecosystem and as such are considered bio-indicators [1]. They represent more than 1,400 different species, or nearly 20% of all recognized mammal species worldwide [2–4]. They possess extremely outstanding qualities such as flight, echolocation, extreme longevity, and unique immunity [5–10]; they are the only flying mammals [11]. These mammals exist in many parts of the globe except the cold regions; they play a significant role in pollinating flowers and dispersing seeds and are highly useful in reforestation [5], [12–15].

While there are enormous benefits associated with bats, there are also some mystic beliefs about these creatures, most of which are associated with negativity, especially in the West African Subregion. Such negative attributes include associations with darkness, witchcraft, vampires, malevolence, and death, among others. The idea that bats are pests and unwelcome neighbors has perpetuated negative sentiments toward these species [16].

The fruit bat population is panmictic across its African range. It is broadly distributed throughout much of sub-Saharan Africa: across lowland rain forest and savannah zones ranging from Senegal in the west to South Africa in the south and Ethiopia in the east [12], [17]. The straw-colored fruit bat, *Eidolon helvum* (*E. helvum*), is widely distributed throughout Nigeria and is the second largest fruit bat species [18]–[21]. It has been reported by [22] that straw-colored fruit bats occupied 79% (357 out of 450 trees) and 34% (34 out of about 100 trees) of the trees on the east and west sides, respectively, of the Nakivubo Channel in Kampala, Uganda. *E. helvum* is said to travel a cumulative distance of over 2,500 km in about 5 months using satellite telemetry [23]–[25].

Artificial intelligence (AI) is rapidly becoming a crucial tool in ecological monitoring, offering a multitude of benefits in curating data on movement patterns, wildlife observations, monitoring ecological populations, and understanding behaviors. It is now possible to recognize, describe, and even count wild creatures in camera-trap photographs thanks to AI technology. The hidden habits of these animals are revealed in ways that humans have never discovered before [26]–[29].

Bats play a crucial role in our ecosystem, making it essential to monitor their movement patterns for foraging and roosting. This monitoring can provide valuable insights into conservation efforts and their overall behavior. This study aims to review previous research on *E. helvum* (straw-colored fruit bat) movement patterns and tracking techniques using the internet of things (IoT) and machine learning (ML).

Fig. 1 Straw-colored fruit bat [30]

2. Classification of Bats

Bats are categorized as mammals in Chiroptera's order [31], [32]. The forelimbs of these mammals have evolved into wings, making them the most distinctive species and the only mammals in the world capable of true flight.

There are more than 1,100 species of this endangered animal type worldwide, accounting for approximately 20% of all mammal species [33]–[36]. Of these, 70% are insectivorous, i.e., they feast on insects such as flies, roaches, and mosquitoes, while the remaining 30% prefer fruits, nectar, or blood [37]–[42]. As some tropical flower species depend on certain smaller kinds of bats for pollination, there may be environmental issues when a bat is introduced in a new area. Significantly, many tropical plants heavily depend on bats, both for pollination and for dispersing their seeds by devouring the fruits that arise [43]–[46].

Megachiroptera (megabats) and Microchiroptera are the two primary suborders into which bats are generally divided (microbats/echolocating bats) [47]–[53]. The factors for categorization into these two sub-orders are based on several factors such as habitat and diet.

Microbats are typically smaller than megabats, although there are exceptions; some large microbats can be larger than certain small megabats [53]–[57]. It is also confirmed by [53, 59–61] that Microchiroptera are characterized by poor sight and, as a result, utilize echolocation pulses for navigation. Some megabats also use echolocation, but they do so in a unique way by producing tongue clicks instead of using the laryngeal echolocation mechanism found in microbats [53, 62–64]. Megabats consume fruit, nectar, or pollen, whereas microbats consume blood, insects, tiny mammals, and fish, using echolocation to locate their prey [65], [66].

3. Straw-Colored Fruit Bat

E. helvum, one of the largest fruit-eating bats in Africa, is renowned for its distinctive morphological, ecological, and reproductive characteristics. It is classified as a megachiropteran and primarily found in

Africa and the southwestern region of the Arabian Peninsula [18], [19], [24], [67]–[69]. The age categorization of *E. helvum* into juvenile, adolescent, and adult is typically determined by the bat's weight and size [69]. Dechmann and van Toor [70] reported that with a wingspan of up to 80 cm, they are capable of traveling far distances. In instances where their colonies are exceptionally large and there is intense competition for food, they fly up to 95 km in search of suitable food trees and return to their roosts at dawn. They contribute immensely to the species and genetic diversity of forests through the seeds they transport and disperse from one point to the other during migration across Africa [71]–[76]. According to predictions, fruit bats could play a crucial role in reforesting regions of Africa where trees have been depleted [70]. However, [18], [77]–[83] found that when spillover occurs, bats have the potential to transmit zoonotic viruses that can impact the health of humans and domestic animals.

4. AI Techniques

To address the challenges and difficulties associated with manually categorizing bats in their natural habitats, particularly in terms of cost, various AI techniques have been utilized. These techniques vary from different IoT techniques and have been implemented to streamline and enhance the categorization process. Numerous researchers have utilized digitalization technologies such as AI, ML, and IoT solutions to effectively categorize these mammals. Wu et al. [1] recorded echolocation cries of two visually similar bat species (Miniopterus magnate and M. fuliginosus) in China for vocal characterization and order. Both species communicated via brief, frequency-modulated, narrow-band echolocation noises. Based on the spectrum characteristics of echolocation calls, 92.3% of all calls recorded were assigned to the proper species. According to this research, echolocation calls can be used to distinguish between bat species that look similar morphologically.

An audio-based convolutional neural network (CNN) system was proposed by [84]. Different echolocation sounds from different bat species were used to train the system. Bat species monitoring was performed in real time using an artificial intelligence of things (AIoT) system. The Long-Range Wide Area Network (LoRaWAN) was used to transfer the classified species instantly after they are received by an application server. Using deep learning frameworks (TensorFlow Lite and TensorRT), the performance of three edge devices (the Raspberry Pi Model, NVIDIA Jetson Nano, and Google Coral) was examined. According to the evaluation, all the devices could make inferences for a 3-s audio segment in less than 0.5 s per inference. Nonetheless, it was found that Google Coral performed better than competitors in terms of speed (0.3917 seconds per audio segment), accuracy, and the lowest CPU use at 29.2%.

Redgwell et al. [85] used ensemble neural networks (ENNs), support vector machines (SVMs), and discriminant function analysis (DFA) to categorize calls from 14 different bat species. SVMs and ENNs both exceeded DFA when the effectiveness of the three separate techniques was compared for all 14 species, and ENNs consistently outperformed SVMs (which had an identification rate of 87%). According to the research, classifying unidentified calls using a quantitative method for echolocation identification yields reliable and repeatable results.

Masuda et al. [86] presented a method for determining bat species based on echolocation noise. A total of 1400 sound files were collected between 1999 and 2019 from 4 families, 13 genera, and 30 species in Japan and South Korea. Sound recordings were used to identify bat echolocation sounds, which were then used to create 54,525 spectrograms using the Fourier transform. To extract the characteristics from the dataset, a CNN with the MobileNetV1 architecture was employed. The Bayesian optimization algorithm and nested cross-validation were used to look for the best possible set of hyperparameters and assess the performance that may be predicted. The study's accuracy rate of 98.1% exceeded that of earlier investigations that covered more than 30 bat species.

Li et al. [87] leveraged recent progress in image recognition using deep learning to facilitate the detection of bat presence in any location. To achieve the aim of this research, different variants of CNNs were explored. Due to the paucity of data, transfer learning was adopted to get the work done. A pool of image dataset curated by the Virginia Department of Transport (VDOT) was used on an image recognition model that gave 92% accuracy. Users can upload pictures of stains on structures and obtain classification outputs from the model using a prototype web-based application. It is anticipated that this application will make bat record surveys and the ensuing conservation struggles easier.

A hierarchical machine learning framework was formulated by [88] to automate the classification of Southeast Asian echolocating bats. The framework was utilized to develop a classifier for Bornean bats, which was tested in the terrain of Sabah. The approach reduces the amount of data that needs to be processed by 86% by allowing users to quickly filter acoustic recordings for common species and identify files of interest. The classifier identifies 85% of calls correctly to 1 of 4 ecological ensembles.

5. Ecological Impact of the Straw-Colored Fruit Bat

Ecology plays a significant role in the lives of humans and other life forms; it plays a crucial role in the survival of living organisms. There remains a critical need to highlight the advantages and positive qualities of bats to counteract the widespread negative perceptions that many individuals hold toward this mammal. The disparity between public perception of animals and their significance to human well-being represents a significant imbalance, particularly in the case of bats [13, 16]. Their disturbance poses a universal threat that contributes to the loss of biodiversity [90]; many bat species are at risk due to habitat loss, climate change, disease, and other concerns [91].

Fruit bats play a crucial role in natural ecosystems by pollinating plants, dispersing seeds, and controlling insect populations that threaten crops [91]. It has been confirmed that *E. helvum* is a significant dietary component for humans in certain regions [93]. However, these animals, which play a crucial role in maintaining a healthy ecosystem, are endangered. It was discovered in [92] that *E. helvum* bats are known for their ability to forage over long distances, setting them apart from other bat species. This unique behavior allows them to provide crucial ecological services across vast areas of land. In addition to their roles in pollination and seed dispersal, it has been found that certain bats possess unique features such as echolocation and membrane wings that have inspired advancements in engineering and scientific innovation [14]. Drones designed with thin and flexible bat-like wings have been developed with more efficient sonar systems for navigation. On this basis, [14] recommended that the population of *E. helvum* should be consciously maintained throughout Africa.

According to [94], straw-colored fruit bats may pollinate trees for up to 88 km and distribute seeds across distances of hundreds of meters to several miles. While foraging, they cover significantly greater distances than most other fruit bats. This ability allows them to provide crucial ecosystem services over a vast expanse of territory. In related research, the African fruit bat colony size and estimates of ecosystem services were linked by [95]. According to the study, the typical bat travels 67.1 km per night to and from its feeding tree to the colony, stopping at one of the three distinct trees. Depending on the colony and season, it disseminates seeds over average distances of 12.6–21.4 km or up to 95 km. Aziz et al. [16] effectively synthesized the current knowledge on the diet of *E. helvum* and its interactions with plants; the research was done based on previous reviews spanning more than 30 years (1985–2020). The dataset was utilized to validate the ecological roles of these mammals and identify economic benefits associated with them.

Costa et al. [90] raised concerns about the implications of wildlife disturbance by humans as it has become a major factor that aids the damage to biodiversity. The disturbance tends to affect animals' behavior and physiology, and this often results in changes in species distribution and richness. The researchers emphasized the importance of implementing AI-driven devices for the conservation of fruit bat species.

Fruit bats may help connect distant plant communities and increase the current plant variety in urban forests. Moreover, they aid in the seed distribution of species crucial to forest regeneration. Pradana and Tsang [96] highlighted the function of fruit bats in plant community changes in Indonesia; an essential consideration for the future is the expansion of green spaces in metropolitan areas to mitigate the adverse impacts of anthropogenic changes.

Given the various views of different researchers on the ecological impact of straw-colored fruit bats, it is obvious that despite negative perceptions and beliefs about this class of mammal, they contribute immensely to the growth and health of our environment and, as a result, enhance the health of its inhabitants. It is crucial to prioritize the preservation of this animal to prevent rapid deforestation and the transformation of our environment into a desert. By serving as pollinators and seed dispersers, this group of bats has the potential to significantly increase plant variety in urban forests and link far-flung plant groups; forest regeneration plays a crucial role in creating green spaces and mitigating the negative impacts of human activities on the environment. This is achieved through the migratory behavior of this mammal species. Their economic significance cannot be overemphasized because of their richness in protein, which makes them a source of food in some African regions [20].

6. Migration and Tracking Techniques

The ecological and economic importance of the straw-colored fruit bat, *Eidolon helvum*, has been established. However, little is known about its movement and migratory patterns. Its foraging behavior is primarily based on assumptions and remains largely unknown. Understanding its ecology will greatly contribute to the effective development of conservation measures. Several researchers and ecologists have explored different approaches to track the migratory behavior of bats.

Richter and Cumming [97] evaluated the causes of the fruit bat migration. Based on the idea that this mammal migrates to take advantage of opportunistic seasonal fluctuations in food supply, several predictions were tested. According to the study, the *E. helvum* colony exhibited a number of unexpected behaviors, such as a propensity for migrating satellite colonies to congregate during the height of food production rather than disperse, and a propensity to travel far beyond the nearest food sources when foraging. More studies are necessary to understand the migration routes, food supplies, habitat requirements, and the function of migration in disease transmission.

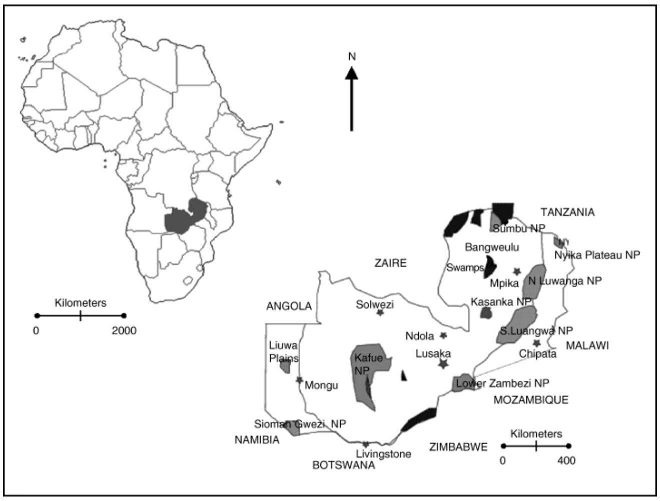

Fig. 2 Map of Zambia's Kasanka National Park. The dotted lines mark the southern and western park boundaries, while the Luwombwa and Mulembo Rivers define the park's northern and eastern boundaries, respectively. Also highlighted are the locations of the E. helvum roost and the vegetation transects where mist netting was conducted (n) and not conducted () [97]

The movement ecology of *E. helvum* was studied by [98] through the analysis of stable element ratios collected from museum specimens. In the study, using two similar straw-colored fruit bats, it was established that the stable isotope method can distinguish between geographically different areas in sub-Saharan Africa. The DFA accurately assigned 84% of individual bats to their capture sites. The study revealed that these mammals originated from an average distance of around 860 km from the collection site, with others journeying from areas roughly 2,000 km distant. The research could infer that stable element ratios can be used to elucidate the drifting pattern of bats.

In a bid to identify the feeding sites of the near-threatened straw-colored fruit bats, experiment in [99] shows a male and a female bat being tagged in the early months of 2019, and data were gathered for 217 and 35 days, respectively, on the island of Anjouan, where the usage of GPS loggers was pioneered. The categorization of location points into behavioral categories was considerably aided by acceleration data. By a cluster analysis on all location points assigned to a behavioral category in which eating might occur, potential feeding sites were found (Fig. 3).

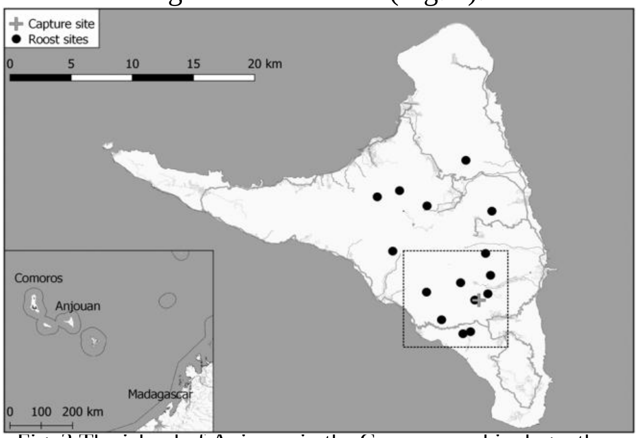

Fig. 3 The island of Anjouan in the Comoros archipelago, the Western Indian Ocean, home to 15 established long-term roost locations of Pteropus livingstonii. Additionally, the map displays the locations of the two captures [99]

Pakula et al. [100] performed an observation of the African straw-colored fruit bat in the Gulf of Guinea. The bat circled the ship for four days at a maximum distance of 100–200 m. The most recent observation was made at a distance of 185 km from land at Sierra Leone's longitude. The outlying Islands of Sao Tome and Principe, which are far from the coast by 230 and 217 km, were considered the bat's origin. In addition, it was anticipated that bats could fly 140 kilometers between those two islands; thus, they looked for a place to land while traveling across the sea.

An investigation on how fruit bats fly with changing wind support was conducted by [101] using GPS loggers to collect data from the bats. It involves measuring the flying speeds, wingbeat frequency, and overall dynamic body acceleration (ODBA) using an integrated triaxial accelerometer to estimate the energetic expenditure. The research findings suggest that there may be potential for flexibility in wingbeat kinematics to optimize the flight efficiency of these animals, resulting in reduced energy expenditure.

In a related work by [102], GPS was also used to study the forage pattern of *E. helvum*. In achieving the aim of the work, high-frequency GPS loggers were used to monitor groups of the mammals, and complete foraging trios were recorded. To understand how social connections affect foraging behavior and performance, proximity-based social networks were built using the GPS data that had been collected. The idea was that if social groups of these bats foraged together to increase food intake, then creatures with closer bonds would frequent the same food patches more frequently, and there would be a correlation between bond strength, increased foraging efficiency, and decreased nocturnal energy expenditure. It was found that the majority of the 18 tracked females foraged 20–30 km away from where they roosted.

The three distinct groups that were tagged employed the same mix of moving and resting for the roughly 200 min that they were outside the cave, as shown in Fig. 4. Only a few foraging patches were used close to the roost during the return flight to the cave, and they used 7.2 + 4.2 foraging patches every night that were 23.35 + 1.4 km away from the roost. They used more patches with an estimate of 0.886 + 0.034, likelihood ratio X21 = 6.861, p = 0.009) as their total nightly flight distance increased. In addition, it was estimated that bats used 20.72 + 19.91 feeding places in the study (flower clusters). However, no correlation was found between the number of feeding groups, the number of patches used, or the amount of time spent outside the roost.

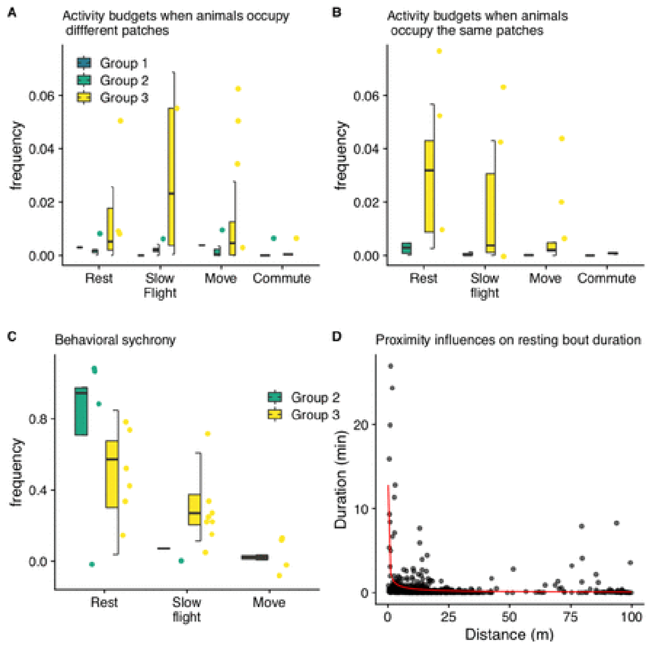

Fig. 2 Impact of proximity on bats: A) activity budgets in different patches, B) activity budgets in the same patch, C) incidence of coordinated behavior surveillance in a shared patch, and D) length of uninterrupted resting periods in relation to the distance of the nearest neighboring bats [102]

O'Mara et al. [103] emphasized the value of utilizing radio and satellite-based telemetry methods for studying animal behavior, with a specific focus on bats. However, researching these mammals poses significant challenges due to their small size and secretive behaviors. During the observation of these mammals, the scientists attached devices exceeding the recommended 5% of body mass. This action lacked sufficient justification and raised concerns regarding the well-being of the animals. The study also examined the methods used to attach devices to the bats, with the most common method being directly adhered to the backs of little bats. The devices remained in place for 9 days, significantly shorter than the average battery life of similar devices. This limited timeframe resulted in incomplete data regarding the overall health, survival, and reproductive success of the bats after the transmitters were attached. The authors developed a collar from biodegradable material designed for small bats. This collar was tested on various animal species. Three out of the four species were successfully fitted with the collar, allowing prolonged adaptation and tracking times. The gadget automatically dropped off once the battery ran out.

A study was conducted by [104] on Hebrew University's new tracking system for monitoring the navigation of fruit bats. The study described how animals mentally positioned themselves in relation to their surroundings. It was found that rather than relying on path directions through multiple landmarks, the bats utilize their cognitive map to navigate with high precision from any location to their foraging area. This cognitive map also helps them recall and return to auspicious fruit trees, roosting sites, and other targets. The researchers developed ATLAS, an advanced inverse GPS tracking system, to tackle the challenge of selecting an efficient tracking tool. The technique was utilized to gather a substantial dataset of 172 Egyptian fruit bats engaged in foraging activities. This dataset comprised over 18 million localizations collected during 3,449 bat nights spanning a four-year period. The mapping of fruit trees across the 88,200-hectare study area, detailed track analysis, and translocation trials were facilitated by the data collected using ATLAS. The findings, as displayed in Fig. 5, provide thorough proof of a cognitive map from any wild animal.

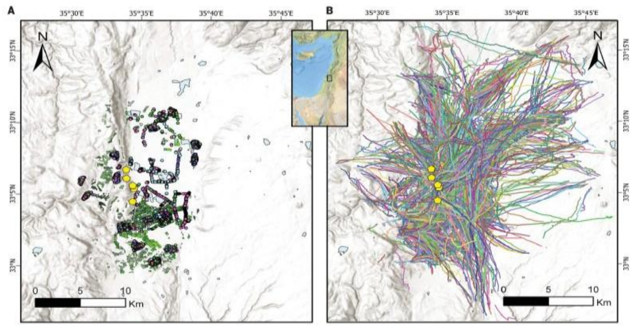

Fig. 3 A) Research region in northern Israel's Hula Valley. Fruit tree orchards are shown by green polygons, and the locations of 14,314 individually mapped fruit trees are marked by color pointers. The five known bat colonies (caves) in the region are identified by yellow pentagons; B) 172 bats' 9218 movement tracks captured by ATLAS (The authors)

Triaxial accelerometers were employed by [105] to recognize daytime flights of roosting straw-colored fruit bats to measure roost disturbance. At five roosts in Ghana, Burkina Faso, and Zambia, 46 E. *helvum* were caught and fitted with dataloggers that had a GPS and an accelerometer. Accelerometer signatures were used to identify daytime roost flights, which were then modeled against our activities in the roosts on days when it rained and the wind was blowing hard. It was discovered that on days of trapping and with rising sun brightness, the likelihood of daytime roost flight increased. The outcomes supported the use of accelerometers to monitor *E. helvum* roost disturbance.

Wieringa et al. [106] focused on identifying the geographic origin of migratory bats by analyzing the trace components in bat fur. Results showed that the food chain, which changes over huge geographic scales, is somehow related to trace elements in the soil. To establish a foundational map for allocation among the diverse species in eastern North America, the authors utilized plasma mass spectrometry to measure the concentrations of 14 trace elements in the fur of 126 known-origin eastern red bats. For each bat, a likelihood of origin map was created using a probabilistic framework, and the accuracy of trace element profiles in predicting the origins of these bats was tested. According to the results, 80% of the time, trace elements enabled the successful assignment of individual bats.

7. Application of AI in a Biodiversity Study

AI has various applications in biodiversity studies, including conservation and sustainable use of biological and ecosystem values [68]. AI can be used to analyze large amounts of data and identify patterns that may not be visible to the human eye, such as tracking animal movements and monitoring changes in ecosystems over time. Machine learning algorithms can be trained on large datasets to identify patterns and predict changes in biodiversity. AI can also be used to analyze satellite imagery and other remote sensing data to monitor changes in land use and habitat loss [45]. AI can help experts make crucial decisions about future biodiversity management by learning from past environmental changes. AI systems can accurately identify species and analyze insect behavior, which can help researchers better understand biodiversity [40]. Overall, AI can revolutionize biodiversity studies by enabling more efficient data collection and analysis, enabling more effective conservation efforts and data-driven decision-making.

Straw-colored fruit bats migrate frequently, and their movement patterns can be captured, stored, analyzed, and presented using AI. Data obtained from this animal movement can have either spatial or temporal dimensions [107], [108]. In contrast to the temporal dimension, which describes how data changes based on time, the spatial dimension discusses how data changes depending on place. Li [91] gathered digital photos taken from bridges, both with and without indications that bats may be present, to create the AI model depicted in Fig. 6; the images were used by the model to learn the characteristics that indicated the presence of bats. To provide users with a platform where they can interactively input photographs of stains on structures and obtain classification outputs from the algorithm, a prototype web application was also constructed.

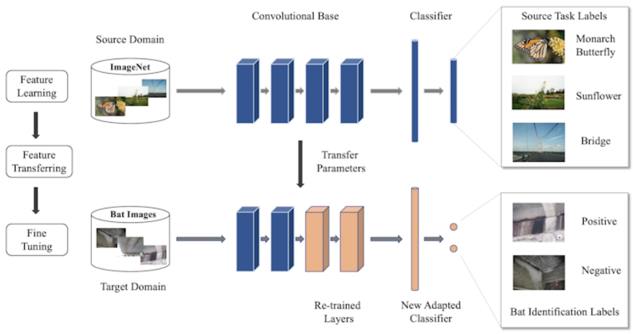

Fig. 4 AI model for bat presence detection [91]

There is a growing interest among researchers in the application of machine learning in biodiversity studies [109]–[111] through big data analytics [112], [113]. Regression models were used in [114] and [115] for spatial prediction based on explanatory analysis of climate and topography. Other machine learning algorithms such as Random Forest have been used to understand patterns in fisheries [116], [117] and mammals [118].

8. Future Directions in AI-Driven Bat Tracking

AI presents many possibilities in agriculture, ecology management, and wildlife conservation. Exploring various approaches associated with AI, such as the IoT, machine learning techniques, and edge computing, presents new opportunities in ecological research.

Machine learning, in recent times, has been an indispensable tool for providing technologically-driven solutions; the integration of edge computing and the IoT offers solutions in environments with limited resources. However, ML tasks entail a large amount of computational power to classify and as well make accurate predictions [119]. The emergence of embedded ML, known as TinyML, is causing a shift in the paradigm from high-end systems to low-end clients. In this case, there is a consistent potential for maintaining the accuracy of the learning model, enabling end-to-end deployment of ML on resource-efficient microedge devices, improving processing capabilities, and ensuring reliability. Adopting TinyML for tracking *E. helvum* movement patterns will extensively reduce power usage and, as a result, provide an opportunity for long periods of data curation and analysis. The issue of power generation constraints on sensors and monitoring devices will be effectively addressed with TinyML; higher efficiency and longer performance are also ensured.

In a related article by [58], TinyML is considered as integrated full stack ML architectures, techniques, tools, and approaches; they can perform on-device analytics for various sensing modalities at extremely high energy efficiency (mW), thereby enabling machine intelligence at the border between the physical and digital worlds. This further asserts the possibility of adopting this technique for tagging sensors placed on migratory fruit bats to learn their movement patterns and identify their roosting locations.

In scenarios with a substantial dataset, deep learning, specifically TinyDL, can be investigated, as demonstrated by [57] in the creation of a deep learning framework called 'Tidzam' for wildlife detection, identification, and geolocalization. The framework demonstrates the application of Deep Learning technology to recognize and detect wildlife activity. However, its ability to recognize and track specific animals and achieve accurate density estimation is still up for debate and will require a significant amount of data gathering and validation. This possibility can also be explored by tracking fruit bat movement styles.

9. Conclusion

The need to conserve the near-threatened species is imperative to sustain ecological health and human well-being. It is crucial to comprehend the population biology of these species to protect them. Long-term monitoring, biodiversity inventories, population censuses, and demographic studies are essential tools in this endeavor [89].

Exploring various techniques for tracking and studying bat movement and foraging patterns has unveiled a plethora of opportunities and advancements in AI that can be leveraged for more precise and efficient tracking of the animals. A few drawbacks are identified in relation to existing popular techniques. One of such drawbacks is the limitation to the size of data that can be obtained through GPS trackers; another is the use of radio telemetry to follow small wild animals, which makes it difficult for researchers to obtain accurate information about their movement over a lengthy period. The need for innovative methods and AI-driven solutions to track wildlife demographics cannot be overemphasized.

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